The Complete Spectral Catalog of Bright BATSE Gamma-Ray Bursts

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Abstract. We present a systematic spectral analysis of 350 bright GRBs observed with BATSE, with high spectral and temporal resolution. Our sample was selected from the complete set of 2704 BATSE GRBs, and included 17 short GRBs. To obtain well-constrained spectral parameters, four different photon models were fitted and the spectral parameters that best represent each spectrum were statistically determined. A thorough analysis was performed on 350 time-integrated and 8459 time-resolved burst spectra. Using the results, we compared time-integrated and time-resolved spectral parameters, and also studied correlations among the parameters and their evolution within each burst. The resulting catalog is the most comprehensive study of spectral properties of GRB prompt emission to date, and provides constraints with exceptional statistics on particle acceleration and emission mechanisms in GRBs.

INTRODUCTION

Previous spectral studies of Gamma-Ray Burst (GRB) prompt emission have shown compelling evidence that a simple emission mechanism cannot entirely account for the observed spectra. However, spectral parameters that provide constraints on GRB emission mechanisms often depend on functional forms used to fit the data, as well as integration timescales of the spectra. A consistent, comprehensive spectral study of GRB prompt emission in large quantity is therefore crucial to unveiling the nature of GRBs.

A total of 2704 GRBs were observed with the Large Area Detectors (LADs) of the Burst and Transient Source Experiment (BATSE) on board the *Compton Gamma-Ray Observatory*, in the energy range of $\sim$ 30 – 1900 keV. BATSE provided the largest database currently available of GRBs from a single experiment, with good spectral and temporal resolution. Many of the BATSE GRBs were bright enough for high-time resolution spectroscopy within the bursts as well as time-integrated spectroscopy. We present here a systematic spectral analysis of 350 bright BATSE GRBs. The sample size is more than twice that of the previous BATSE spectral catalog [1], which included only time-resolved spectroscopy. Our analysis included 350 time-integrated spectra and 8459 time-resolved spectra, and four different photon models were used to fit all the spectra. The resulting catalog is the largest and most comprehensive study to date of GRB prompt emission spectra.

THE ANALYSIS

To assure sufficiently good statistics, we selected the 350 brightest GRBs from the entire BATSE database, with either the peak photon flux (256 ms, 50 – 300 keV) $>$ 10 photons s^{-1} cm^{-2} or the total energy fluence (30 – 2000 keV) $> 2 \times 10^{-5}$ ergs cm^{-2}.

One of eight BATSE modules consisted of a LAD and a Spectroscopy Detector (SD). In this work, we used only the LAD data, which provided higher sensitivity, to make the analysis more consistent throughout. In addition, a problem recently identified with the SD response matrices above $\sim$ 3 MeV could render the SD data unreliable for spectral analysis at high energies [2]. The LAD data types used for the analysis are, in order of priority, High-Energy Resolution Burst (HERB), Medium Energy Resolution (MER), and Continuous (CONT) data [see 1, for BATSE data types]. All LADs were gain-stabilized with the usable energy range of $\sim$ 30 – 1900 keV. We binned the spectra in time so that each resolved spectrum has signal $> 45\sigma$ above background. An integrated spectrum is the sum of all the resolved spectra within the burst, and most integrated spectra cover the time range of T_{90}.

We used four photon models to fit each spectrum. Each photon model consists of two, three, four, and five free parameters, respectively in the order shown below.

1. **Power Law Model (PWRL)**

$$f_{\mathrm{PWRL}}(E) = A\left(\frac{E}{100\mathrm{keV}}\right)^{\lambda}$$

Parameters: A = amplitude (photons s^{-1} cm^{-2} keV^{-1}) and λ = spectral index

2. **Comptonized Model (COMP)**

$$f_{\mathrm{COMP}}(E) = A\left(\frac{E}{100\mathrm{keV}}\right)^{\alpha}\exp\left(-\frac{E(2+\alpha)}{E_{\mathrm{peak}}}\right)$$

Parameters: A, α = low-energy spectral index, and $E_{\mathrm{peak}} = \nu F_{\nu}$ peak energy (keV)

3. **GRB Model (BAND)** [3]

$$f_{\mathrm{BAND}}(E) = \begin{cases} A\left(\frac{E}{100\mathrm{keV}}\right)^{\alpha}\exp\left(-\frac{E(2+\alpha)}{E_{\mathrm{peak}}}\right) & \text{if } E < (\alpha-\beta)\frac{E_{\mathrm{peak}}}{2+\alpha} \\ A\left[\frac{(\alpha-\beta)E_{\mathrm{peak}}}{(2+\alpha)100\mathrm{keV}}\right]^{\alpha-\beta}\exp(\beta-\alpha)\left(\frac{E}{100\mathrm{keV}}\right)^{\beta} & \text{if } E \geq (\alpha-\beta)\frac{E_{\mathrm{peak}}}{2+\alpha} \end{cases}$$

Parameters: A, α, β = high-energy spectral index, and E_{peak}

4. **Smoothly-Broken Power Law Model (SBPL)** [4, 5]

$$f_{\mathrm{SBPL}}(E) = A\left(\frac{E}{100\mathrm{keV}}\right)^{b} 10^{(a-a_{\mathrm{piv}})}$$

$$\text{where} \quad a = m\Lambda\ln\left(\frac{e^{q}+e^{-q}}{2}\right) \qquad a_{\mathrm{piv}} = m\Lambda\ln\left(\frac{e^{q_{\mathrm{piv}}}+e^{-q_{\mathrm{piv}}}}{2}\right) \qquad q = \frac{\log(E/E_{\mathrm{b}})}{\Lambda}$$

$$q_{\mathrm{piv}} = \frac{\log(100\mathrm{keV}/E_{\mathrm{b}})}{\Lambda} \qquad m = \frac{\lambda_2-\lambda_1}{2} \qquad b = \frac{\lambda_1+\lambda_2}{2}$$

Parameters: A, λ_1, λ_2 = low- & high-energy spectral indices, E_{b} = spectral break energy (keV), and Λ = break scale (decades of energy)

THE RESULTS

We fitted the four photon models to each of the 350 integrated spectra and 8459 resolved spectra. From the overall performance of each model in fitting all spectra, determined by the χ^2 of the fits, we found that many spectra were fitted adequately by multiple photon models. We also confirmed that the low-energy index, α, of BAND and COMP models tends to be harder than the low-energy index λ_1 of SBPL.

Model Comparison within Each Spectrum. To find the model that best describes each spectrum (referred to as "BEST" here), we looked for significant improvements in χ^2 when fitted by more complicated models with more parameters, starting from the simplest PWRL model. When the significant improvements were found, we also required the additional parameters to be sufficiently constrained, to assure the parameters are meaningful and are indeed needed to represent the spectra. We found that the majority of the spectra required BAND or SBPL. COMP was considered BEST in much larger fraction of the resolved spectra than the integrated ones due to the existence of no-high-energy spectra within bursts as well as the lower signal-to-noise ratio. The distributions of the BEST spectral parameters for both integrated and resolved spectra are shown in Figure 1. To account for the difference between the low-energy indices of BAND, COMP, and SBPL, we use here the "effective α" [6, 7], the tangential slope in log scale at 25 keV, as the low-energy index where BEST is BAND or COMP. The effective α and λ_1 generally agree within 1σ. $E_{\rm peak}$ is the peak energy of the νF_ν spectrum, regardless of the photon model used.

Integrated vs. Resolved. For the comparison between the integrated and resolved parameter distributions (Figure 1), we calculated the Kolmogorov-Smirnov probabilities and statistics ($P_{\rm KS}$ and $D_{\rm KS}$) for the null hypothesis of two distributions being consistent. We found a significant difference ($P_{\rm KS} \sim 10^{-16}$, $D_{\rm KS} = 0.23$) between the low-energy index distributions, and a moderate difference ($P_{\rm KS} \sim 10^{-2}$, $D_{\rm KS} = 0.10$) between their $E_{\rm peak}$ distributions. This is due to spectral evolution within bursts, commonly observed.

Spectral Parameter Evolution & Correlations. An example of the BEST spectral parameter evolution within a burst is shown in Figure 2. In this case, both the low-energy index and $E_{\rm peak}$ evolve from hard to soft, and the models with fewer parameters (PWRL,

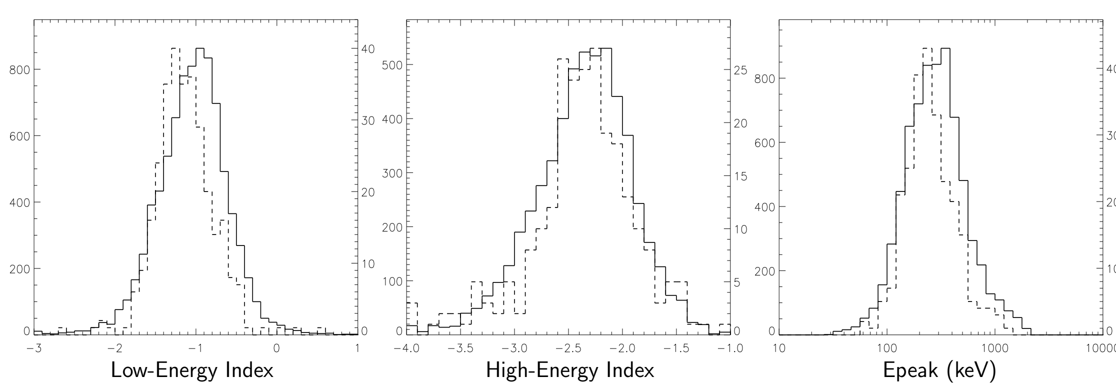

FIGURE 1. Comparison of BEST parameter distributions of integrated (dashed; right axis) and resolved spectra (solid; left axis). The last bins include values outside the edge values.

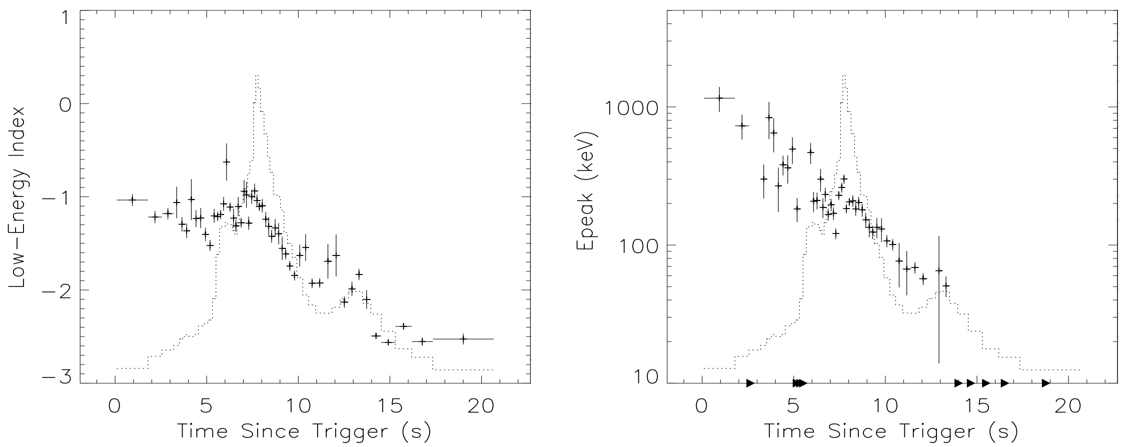

FIGURE 2. The BEST spectral parameter evolution of GRB 950403. Photon flux is overplotted as dotted lines. The arrowheads in $E_{\rm peak}$ plot indicate where the values cannot be determined.

COMP) are BEST at the tail as the burst spectra become softer. Within each burst, we also searched for the Spearman rank-order correlations among the BEST spectral parameters. The most significant ($> 3\sigma$) positive correlation was found between the $E_{\rm peak}$ and the low-energy index in the largest fraction of GRBs (26%).

Short GRBs. Our sample included 17 short GRBs ($T_{90} < 2$ s), three of which were bright enough for time-resolved spectral analysis. Within these three short GRBs, spectral evolution (either hard-to-soft or photon-flux tracking behavior) was clearly observed. However, we did not find any significant differences in the spectral parameters between the 17 short GRBs and long GRBs in our sample. A possible reason for this is the fact that only bright GRBs are considered here, which tend to be harder [8].

CONCLUSIONS

The GRB spectral database obtained in this work is derived from the most sensitive and largest database currently available. Therefore, these results set a standard for spectral properties of GRB prompt emission with exceptional statistics. Our results can provide reliable constraints for existing and future theoretical models of GRB emission and particle acceleration mechanisms.

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